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THE EFFECTS OF PHYSICAL FATIGUE ON MENTAL EFFICIENCY.
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The Effects of Physical Fatigue on Mental Efficiency.

FLOYD CARLTON DOCKERAY.

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INTRODUCTION.

THERE are three possible effects of physical fatigue upon mental efficiency: (*a*) It may produce decreased mental efficiency, either in the speed or accuracy of the work, or in both; (*b*) it may serve as an incentive to greater effort and

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thus increase the efficiency; or, (*c*) it may have no appreciable effect in either direction. Furthermore, it might be assumed that all these effects might be manifested in the same individual under different physical conditions, or that, given a definite amount of physical fatigue, individuals might be divided into groups according to the effects produced. It might also be supposed that the immediate effects would not necessarily be the same as those to be noted later, say in a half hour, or even after a longer time. The immediate effects of physical fatigue on mental efficiency are all with which we are directly concerned in this paper. Though the later effects may be of even greater importance, the amount of time involved in such tests has made it impossible to collect sufficient data to warrant their incorporation here.

HISTORICAL.

As Max Offner (31) has reviewed the literature dealing with the various phases of fatigue as they affect the problem of school hygiene, and as C. D. Yoakum (50) gives a very thorough review of the general field, it is not deemed advisable to attempt a discussion of the subject here, except those phases which bear more directly upon the relation between physical and mental fatigue.

Mosso (30) seems to be the first to call attention to the possible relation of physical and mental fatigue. He found with the ergograph which he invented that after voluntary contraction of the finger was no longer possible the finger could still be made to lift the weight if an electric stimulus was applied to the flexor muscle. If the subject was mentally fatigued by lecturing, or by a two-hour examination, the amount of voluntary work he could do on the ergograph was decreased, and the muscle failed to respond to the same extent to the electric stimulus that it did before mental fatigue. It would appear, therefore, that mental fatigue had a direct influence upon the voluntary muscles. However, not all of Mosso's subjects were in complete agreement. Under normal conditions part of the subjects produced convex curves and part concave curves. Only those with concave curves showed reduced muscular ability immediately after mental work. Those with convex curves showed an increase immediately after the mental work, followed an hour later by a decrease.

Mosso considers this difference to indicate merely different types of individuals. Mental work causes not only fatigue but a heightened emotional state, which endures longer with one class than with the other. This heightened emotion causes the greater muscular activity in some individuals. As an explanation of the fact that mental work does have an influence on the ergographic tracings he suggests two possibilities: (1) The muscles might cede a part of their nutriment to the nervous elements, as in fasting. But the muscles rapidly recover after the fast is broken, while the weakness known as fatigue requires time and sleep. (2) There is a fatigue product generated which circulates in the blood and makes fatigue general. This he demonstrated by the transfusion of blood from a dog that had been kept running for several hours into a dog that had rested for the same period. The second dog showed all the signs of fatigue manifested by the first dog. The work of Mosso has been somewhat criticized by later investigators. The amount of physical exercise involved in lecturing is a very important factor which no doubt would affect the ergographic results, but which he neglects to take into consideration. Also, his tests were not repeated sufficiently to secure a constant tendency under a particular set of conditions.

Lombard (24), working with a Mosso ergograph, found that the voluntary contraction of the muscle gave rhythms of contraction which still appeared when the muscle was massaged. When the muscle was caused to contract by the application of an electric stimulus until it could no longer lift the weight, it would still respond to a voluntary stimulus. Furthermore, when one finger was fatigued by voluntary contraction, another finger would give as great a curve as before. He also found that in some individuals there are periods of muscular ability and intervals of inability which succeed each other more or less regularly after the first period of fatigue, even though the will is applied uniformly at the maximum throughout the experiment. These later changes did not appear when the nerves or muscles were stimulated electrically. He concluded that while the fatigue from voluntary contraction must be of central origin, it must lie between the "will center" and the centrifugal nerves. The central origin of fatigue was also evidenced by Joteyko's (17) ergographic

studies, though she found the end plates in the muscles fatigued first. In her experiments fatigue of the right hand decreased the power of the left, which would seem to be a slight contradiction of Lombard's results.

Since these early ergographic studies the possibilities of the application of the ergographic curve as a means of testing mental fatigue has been assumed by many investigators of the problem in the public schools with very contradictory results. Kemsies (20) found, for example, that (1) Monday and Tuesday are the best days of the week; (2) the first two hours of the day are the best of the day, except on Monday; and (3) vacations of not more than three weeks show a beneficial influence in proportion to their length. It was believed that the mental work of the schoolroom produced the decrease in the ergographic tracings, and that there was not complete recovery from one day to the next.

Bolton (3) tested the method more thoroughly in connection with other tests after both physical and mental fatigue. His results for five tests each showed that the performances with the ergograph were considerably increased after two-hour periods of adding, decreased after two-hour walks, and remained unchanged after two-hour rest periods. However, he was not satisfied that the ergograph was a reliable test. Keller (19), on the other hand, used the same method to test the fatigue induced by rapid reading, and found slight indications of fatigue. Ellis and Shipe (11) repeated Keller's experiment, with the result that, while reading showed fatigue, it was not evidenced by the ergographic curves.

The dynamometer has been used frequently as a more convenient method of determining muscular ability after mental work, but the results are even more variable than those obtained by the ergographic method. This may be due largely to the purely accidental factors that may enter into so brief a test. The physical and mental adjustments at the moment are liable to greater variation than would be possible in a longer test. It is also possible that the subject is able to concentrate his effort for the moment required, and obscure the fatigue effects. Direct correlation between mental fatigue and the dynamometric readings was shown by Binet and Henri (4), and their results were confirmed by Clavière (8). The latter divided school children into three groups. To the

first group he gave difficult lessons; to the second group, easy lessons; and to the third group, rest for the same period. The tests correlated with the groups. Thorndike (38) repeated similar tests, but found no correlation.

Reaction times and the spatial threshold as tests of fatigue have been used, but the greatest fault with either method is the great difficulty in determining what function is measured. Considerable dispute has arisen as to whether change in reaction time is a function of a change in the sensory or motor process or in attention. Scripture (34) found that "fatigue in reaction time increases with the complexity of the adjustments required for perceiving the stimulus. There is least fatigue when only an act of attention is involved." (p. 19.) Milroy (27) used one subject on continuous reactions, and found longer reaction times in the last half of the interval, but changing the sense organ did not interfere with the retardation.

The most careful study of physical fatigue by means of reaction times was done by Bettman (1). Unfortunately he was the only subject for the experiments. He performed the experiments, with the aid of an assistant, during vacation, under as uniform conditions, so far as diet, sleep, etc., are concerned, as is possible. The tests consisted of fifty choice reactions before and three hundred choice reactions immediately following the work or the rest periods. He either walked two hours, added one hour, or rested one hour. The results showed an increase in reaction time after mental work and a decrease after physical work, though the greater number of false reactions in the latter case is considered as evidence of decreased mental activity after physical work also. He also employed in place of the three hundred choice reactions a combination of fifty choice reactions, a half hour of adding and a half hour learning nonsense syllables. In these tests, also, he found a decrease in mental activity after either form of work.

The æsthesiometer method has been more widely used as a test of fatigue, but is open to some of the same objections as the reactions test. The chief fault, however, is the brevity of the test as frequently used. Griesbach (13), for example, was able to examine six to ten subjects in ten minutes. Any one familiar with the two-point threshold experiment would expect variations that would obscure the real character of the

results in a test that required only one minute. Bolton (3), in fact, worked with the method in Kraeplin's laboratory, and found marked variations which he ascribes to after-images, tingling sensations and the varying sensibility of the neighboring portions of the skin. These variations obscured any possible evidence of fatigue after adding one hour or walking two hours. Nevertheless, Griesbach (13), Wagner (44) and Vannod (41) have obtained results which they are satisfied show a definite increase in the spatial threshold of the skin after work, principally after gymnastic exercise; and in a later investigation Griesbach (14) has not only considered this a measure of fatigue, but he finds that, while the spatial threshold for both sides of the body may be increased with fatigue, the increase is greater on one side or the other, depending on the nature of the exercise. Thus, for physical exercise, he finds a decrease in sensitivity of the left side of the body, or a decrease in discriminability of the right hemisphere. The experiments were performed upon forty-six soldiers at six to seven o'clock in the morning. The soldiers then marched several miles to their drill grounds and spent the remainder of the time until ten o'clock in general gymnastic exercise. The men were taken from the field, one at a time, and again tested. The pulse rate was found to be much higher and the average threshold value on the left side of the body was greatly increased for every subject. The average increase for the right side was only slight, and many subjects showed decreases.

The chemical products of fatigue are of particular interest to our problem. The presence of sarcolactic acid and potassium with fatigue easily leads to the assumption, as similar phenomena did for Mosso (30), that their circulation in the blood must cause general fatigue. It may be that some day the physiologist can demonstrate the presence or absence of these substances in the cerebral centers following muscular fatigue. At present the experiments are confined to their effect upon the muscles and motor fibers. As early as 1865 Ranke (33) found that the injection of a small amount of lactic acid increased and a larger amount decreased the irritability of an isolated muscle. Recently these experiments have been repeated more extensively by Lee (21) and by Burridge (6). By the introduction of fatigue substances in small amounts

for long times, or in larger amounts for shorter times, Lee produced an increase in the height of the work curve. Still larger amounts produced a decrease at once. Burridge's results lead him to believe that "a quick recovery is to be associated with potassium salts alone or in excess while a slow and prolonged one has only been obtained as an effect of lactic acid. It has also been shown that the effect of an exhausting tetanus is almost identically the same as that found to occur when a high concentration of lactic acid has been perfused through a muscle. There is thus reason to believe that the results noted in the early stages of fatigue are mainly referable to potassium and those of the later stages to lactic acid." (p. 303.) The results of these investigations, particularly Lee's, conform to what is generally observed in the fatigue curve of an isolated muscle, or the curve from voluntary contraction. Hough (16) and Lee show that the fatigue substances also affect the nerve fibers as well as the muscles.

The relation of the fatigue products to mental fatigue has been little studied. Lehmann (22) measured the amount of carbon dioxide exhaled during mental work. He found that mental work of a determined kind and amount has, with the same individual, a constant increase in the amount of carbon dioxide and corresponds to a definite energy measure.

To summarize, we find the relation of physical and mental fatigue much in dispute. Mosso finds fatigue general; Lombard considers it special, but of central origin; while Joteyko's work would indicate that it is partially of central origin and more or less general in character, through the fatigue of the voluntary center. Many of the other tests have been too carelessly performed, or by their nature have been inadequate, to throw much light on the subject. The only experiments which in any way correspond to the experiments to be reported are those of Bettmann and of Bolton. The former, unfortunately, tested only one subject. The latter, though his work was thorough, aimed to test methods that he considered unreliable, and consequently his work throws little light upon the relation of physical fatigue to mental efficiency.

METHODS AND RESULTS.

The experiments were undertaken in the psychological laboratory of the University of Kansas in 1910, and continued until 1915. During the summer the work was carried on at the University of Michigan. The author is indebted to Professor Pillsbury for suggesting the problem and for many suggestions relating to the procedure. Especially deserving of gratitude are those who have given so faithfully of their time and energy as subjects for these experiments, which were of necessity decidedly irksome. The subjects in the University of Kansas laboratory were Professor D. C. Rogers, E. D. Campbell, instructor in logic, and George Babb, Raymond Edwards, William Hoyt, Verne Miner, Emily Berger, George Bunn and Carl Brown, all advanced students in psychology, except Mr. Bunn, a sophomore engineer, who was employed in the laboratory as mechanic. In the Michigan laboratory Professor John F. Shepard, and W. H. Batson, R. I. Cook, J. E. De Camp, and C. S. Wang, graduate students in psychology, were subjects.

ADDITION TEST.

The first test to be used was the addition of figures. The test differed from the Kraepelin tests in that the numbers to be added were in single columns of twenty numbers each, and the subject added the whole column and wrote the sum at the bottom. In the Kreapelin tests the subject added only two numbers at a time. He might, or might not, write the sum. There are two advantages in this method: (1) it is slightly more difficult to add and retain the sum of twenty numbers than it is of two numbers as in the Kraepelin method; and (2) it provides an easy means of determining the accuracy as well as the speed of the operations without any serious interference from writing the sums. In fact it was found that the subjects soon acquired the habit of beginning to add the second column before the answer to the first was entirely written. All subjects were given a few days' training, though not enough to render further improvement negligible, for it was believed that, while the subjects should be familiar with the method, it was not necessary to eliminate improvement entirely. The tests, of fifteen minutes' duration, preceded and followed an interval of fifteen or twenty minutes. The validity of a test of this length will be discussed later.

Tables I*a* and I*b* show the results obtained from three subjects. Ba. and Da. were strong, healthy men, accustomed to all sorts of gymnastic exercises, including running, swimming and tumbling. Ca. was decidedly of the opposite type, and unaccustomed to any sort of robust exercise. Accordingly the same physical work done by him should represent more fatigue. The physical work done by Ca. and Da. consisted in a uniform exercise with the ordinary wall machine of the gymnasium. The subject stood with feet together and bent the back until the hands were on a level with the knees. From this position he rose to the erect position with the hands above the head. This movement was repeated thirty times per minute for from five to twenty minutes. The weight varied as indicated in Table I. Ba. ran various distances on the indoor track. These distances were not run at the subject's best speed, but at a fairly fast rate, which did not vary materially throughout the interval. This uniformity was maintained by the subject setting a standard rate which he considered almost his best for the distance to be run. At the end of each lap he was informed as to whether he had run faster or slower than the standard that had been established.

MULTIPLICATION TEST.

It was soon found that for most subjects at our disposal the simple addition of single figures was inclined to become so automatic that it was doubtful if it required enough attention to be considered a good test. Frequently a subject would report that he heard conversation in the adjoining rooms, but did not feel disturbed in his work. He might even give slight attention to other subjects without affecting the results sufficiently to be detected in the records. For this reason it was considered best to substitute a test that would demand the most careful attention on the part of the subject, and at the same time would not require elaborate apparatus. After the consideration of several tests "cross multiplication" was chosen. The subject was given a series of problems of two or three place numbers, one below the other (the digits 1 and 0 were never used), and instructed to multiply as rapidly as possible and still be accurate. He was allowed to record the partial final product as it was obtained. That is, in such

a problem as $\frac{374}{568}$, the operations were performed as follows: 8×4, record 2; $(8 \times 7) + 3 + (6 \times 4)$, record 3; $(8 \times 3) + 8 + (5 \times 4) + (6 \times 7)$, record 4; $(6 \times 3) + 9 + (5 \times 7)$, record 3; $(5 \times 3) + 6$, record 21. The problems were not so difficult, therefore, as in Thorndike's (37) tests, but the subjects were able to perform more of them in a given length of time. Many of my subjects, moreover, found it next to impossible to retain the total product until the entire problem was finished.

It was difficult to determine what should be considered the unit operation for computing the mistakes. The units place in the total product involves one multiplication, the tens place involves two multiplications and one addition, and so on. Furthermore, a mistake in the tens place might show itself in the hundreds and not in the tens place at all. It was finally decided to consider a problem wrong that was not entirely correct. While this method allowed rather wide variations that could not be recorded, it seemed to be as nearly accurate as any other method that could be devised.

In order to test the effect of the fatigue of a small group of muscles as compared with the more general physical fatigue of the whole body, or at least of a much larger group of muscles, two types of ergographs were used. One consisted of a small spring about six inches long suspended between two vertical bars. Beneath the spring hung a brass band into which the thumb of the left hand was inserted. The whole ergograph was mounted on a small board raised to the level of the arm-rest. The arm was strapped to the arm-rest, palm up, with the fingers under the board supporting the ergograph. A downward pressure with the thumb, therefore, was accompanied by contraction of the flexors of the four fingers as well as of the thumb. The principal fatigue, however, seemed to be felt in the muscles controlling the thumb. The contractions were recorded on the kymograph by means of a marker attached to the spring. The more general fatigue was secured by means of a heavy spiral spring mounted in an iron tube about two feet long and three inches in diameter. The tube was attached in the vertical position to a plank base two feet square. A heavy rod was attached to the lower end of the spring and projected about a foot above the top

of the tube. The upper end of this rod was threaded so that a handle could be adjusted at any height desired. A pointer projected through a slit in the side of the tube and indicated in hundred pounds the tension on the spring. A thread ran from the lower end of the rod through the base, under two pulleys and up through the edge of the base. This thread could be attached to the marker that recorded the results on the kymograph. This furnished a somewhat different sort of exercise from the weights used in the earlier experiments. In place of the long sweeping motion in swinging the arms from the knees to above the head, an exertion of two hundred pounds caused a movement of the handles of the ergograph of about five-eighths of an inch.

Co. and De. were tested at the same hour, one with the thumb ergograph and the other with the body ergograph. The next day their places were reversed, and on the third day both rested between tests. Do. worked with the wall machine, the ten-minute work periods being begun first and the twenty-minute periods undertaken as the subject felt capable of the longer period. Consequently the twenty-minute periods do not represent exactly twice the fatigue produced by the ten-minute periods, though they alternated with the later ten-minute periods. As Do. worked alone, it was necessary to arrange some sort of a signal to announce the end of the test period. It was found that a stop-watch directly beside the problems on the table was satisfactory. A glance at the watch would indicate the time. While this interfered somewhat with the last problem or two, it was believed the interference was slight. However, it is well to keep this difference in method in mind when considering his results. It was not thought wise to attempt the subdivisions into five-minute periods. The physical work of Ba. was similar to that with the addition tests, supplemented by cross-country running, which was over hills and rough roads and was considered by the subject more fatiguing than a longer distance on the indoor track. The results are shown in Tables II*a* and II*b*.

SOUNDER TEST.

A simple attention test was planned for the third series. Pillsbury (32) has suggested the attention wave as obtained with the minimal light as a measure of fatigue, and MacDougall (26) has proposed the marking of dots as they appear

through an apperture in irregular order. The difficulty with the latter is that it involves a large proportion of motor activity to the degree of attention required. While the attention wave with the minimal light has in general proved satisfactory in the Michigan laboratory, special conditions in the present series made an alteration of the test seem advisable. The sounder test was first suggested by Professor Shepard. Four telegraph sounders were selected with as nearly the same quality of sound as possible, and adjusted to approximately the same intensity. A short piece of rubber tubing was slipped on the end of the hammer of each sounder to render the back stroke inaudible. In parallel with each sounder was a recorder and a rheostat. The recorders were adjusted to write less than a quarter inch apart (in later experiments, one-eighth inch apart) on the smoked paper of the kymograph. A fifth recorder wrote in the same vertical line with these. It was connected with the subject's key and recorded his reactions. The sounders were operated by four keys arranged in a convenient row. The subject to be tested sat at a table several feet from the sounders, with his hand upon his key. The experimenter operated one of the sounders several times in rapid succession (six times in two seconds) as a signal. He then operated the four sounders one second apart in irregular order for one minute. The subject was to react to the "signal" sounder, whenever he recognized it, by pressing his key. At the end of the minute the operator signaled with another sounder, to which the subject was to react for the next minute. This was continued for sixteen minutes, the four sounders being used as the "signal" sounder once in each four-minute period, but not in the same order.

The records were preserved upon smoked paper belts about ten feet long. As the markers wrote closely together and the paper traveled fairly fast, and thus spread out the marks horizontally, it was an easy matter to count the number of omissions and errors (wrong reactions). The signal at the beginning of each minute required two seconds. There were, therefore, fifty-eight clicks each minute. The one exception was in the records of Do. The experimenter in this series did not use a stop watch or metronome as a guide, as in the other series, but operated the sounders at a convenient rate, which was somewhat faster than one per second. In all the series the

effort was made to make the order as irregular as possible, and at the same time sound each sounder approximately an equal number of times. It was found, however, that sounder number three (operated with third finger) got the preference, followed by two, one and four. There was also a difference in the difficulty with which the sounders were distinguished. Numbers two and three were most difficult and most often confused with each other.

As might be expected, some subjects could distinguish the sounders more easily than others. Thus the test was found to be very easy for some subjects and difficult for others. Necessarily it would be as poor a test for either extreme. The sounders could not be adjusted for each subject. The method finally hit upon was the introduction of a fifth sounder which should sound simultaneously with each of the others, and the intensity of which could be adjusted readily. The best means of making this adjustment was found to be to adjust it so as to obscure almost completely the difference in the other sounders. Then, by inserting one or more thin papers under the hammer, the intensity could be reduced and the differences in the other sounders made more distinguishable. For some subjects two papers were used; for others one paper was sufficient, and for one subject, De., no paper at all was necessary.

The average number of clicks in each four-minute period to which the subject should react is given in the first column of Table III*a*, followed in the second column by the average number of times he did not react, and in the third column the average number of times that he reacted wrongly. Though in reality both failures to react and wrong reactions are errors, for the sake of brevity we will speak of the former as "omissions" and the latter as "errors." The quality of the work done is expressed in this series negatively, that is, an increase in per cent means a decrease in efficiency, as it is the mistakes instead of the successes that are recorded. The per cent of omissions and the per cent of errors, given in the fourth and fifth columns, are based on the first column, though the per cent of errors might just as reasonably have been based upon the average of all sounders, that is, 232. The totals given in Table III*a* are computed directly from the corresponding columns of the four periods into which the tests were divided, while the results shown in Table III*b* were determined

from the totals of the individual daily records. The two sets of results do not, therefore, agree perfectly, but whenever there is any divergency, Table III*b* should be considered the more exact. In Table III*b* the per cent of increase or decrease in the second test is determined by dividing the per cents of omissions and errors of the second test by the corresponding number of the first test.

Two of the subjects walked between tests for two to three hours' traveling distances ranging from nine to fifteen miles, as recorded by the pedometer. As these walks occurred but once each week, and as neither subject was accustomed to much walking, they were very fatiguing. The other six subjects used the big spring ergograph already described. However, it had been found that the subjects suffered so much from sore hands after the first day that they were unable to lift sufficiently hard to render themselves very fatigued. Accordingly a harness was introduced, which consisted of a padded strap over each shoulder and attached to tugs in front and behind. The subject stood astride the ergograph and the tugs were attached to the handles of the ergograph and shortened sufficiently that the subject could stand erect only when he lifted his maximum amount. This meant that he was always under strain, for when he was not lifting, he was standing in an awkward position that was in itself fatiguing.

ASSOCIATION TEST.

In the association tests nonsense syllables were used, and the method was the usual method of successes. The apparatus used to expose the syllables was the Wirth form made by Zimmermann, slightly modified. Ten pairs of syllables usually constituted a series. As there are fourteen spaces in the cylinder of this apparatus, this left four blanks. The syllables were always arranged so these blanks came together at the end of the series. In the case of one subject, R., these blanks were filled, making fourteen pairs of syllables. Four seconds, counted by the metronome, were allowed for each space, including the blanks. The number of repetitions of the series was determined for each subject by preliminary tests. An approximate average of seventy-five per cent for the normal score was chosen, but in some cases it was found necessary to accept a lower score, as some subjects required more time than was available to reach the higher score. The number of

repetitions was, therefore, twenty-five or thirty, but always the same number for any given individual. The tests of recall were always made the next day, after a definite interval, which was always uniform for a given individual, though for some it was not twenty-four hours. The Hipp chronoscope, prepared for a make-and-break circuit, was connected with the memory apparatus to measure the time between exposure and response. In calculating the per cent of correct responses, all syllables which had formed sensible associations were discarded, except for one subject, R. In his case it was found practically impossible to learn nonsense material when he did not form sensible associations with the syllables. An examination of his records shows that he was fairly constant, when given freedom to associate the material as he chose. I therefore feel that it is allowable to include his records, though they will deserve separate consideration. After discarding some of the results, as mentioned above, those that remained were used as a basis for determining the per cents. Those responses that had one letter wrong were considered equal to one-half, and those with more than one letter wrong were valued at zero. In a few cases a syllable might be completely reversed. If the first and last consonants were very similar, such responses were evaluated one-half. This occurred in only a very few instances. The average time for the responses was calculated from those responses that were considered wholly or partially correct.

Two of the subjects, Do. and H., learned the series Sundays at 11:30 a. m. and tested the next day at 7:30 a. m. Subjects Br., R. and E. learned at 3:30 p. m. twice a week, and tested the following days at the same hour. At least one day intervened between one test and learning the next series. Part of M.'s work was done at 10:30 a. m., and an equal amount at 4:30 p. m., but always the period was preceded by an hour of rest from any strenuous work, and an equal number of rest and fatigue days were given at either hour. His tests were twenty-four hours later. The fatigue exercise consisted of long walks of from nine to fifteen miles for Do. and H., twenty minutes in the harness for Br., R. and M., and five-mile runs for E. The results are given in Tables IV*a* and IV*b*.

Throughout all the tests an effort was made to preserve a reasonable regularity in the subject's general condition. By

"reasonable regularity" is meant the average normal condition of the individual subjects. No restraint was put upon a subject who was in the habit of using tobacco or other stimulant, other than to require that he should not alter his habit preceding a test. It was considered that a man who smokes would be more normal if allowed to smoke as usual than he would be if this were prohibited temporarily. The days for the tests were chosen that were freest from fatiguing occupations for each subject concerned. If for any cause a subject did not feel that he was normal on a certain day, the test was deferred. While some tests were taken with some subjects in the late afternoon, they were always preceded by rest or a day of light work, which was fairly constant for the different days.

METHODS OF TABULATING RESULTS.

Tables I*a*, II*a* and III*a* give the averages of results by periods of five or of four minutes. It would be reasonable to expect that where averages are given, some means of showing how nearly the individual results conform to the average would be given also. The inconsistency of stating an average without stating the mean variation, at least, is recognized. But, granting the inconsistency, it is believed that these tables justify their presence in this discussion. The reasons for the incompleteness of these tables are: First, neither averages nor mean variations of the periods from day to day are very important for our purpose. We are interested principally in the differences between the forework period and the after-work period of the same day. In the second place, these tables are already large. The addition of mean variations for every average would make them too confusing. A further discussion of the results of these tables will be found in the discussion of the curve of work (p. 236). Tables I*b*, II*b* and III*b* present the totals of results for each day, and the per cent of increase or decrease in the second test when compared with the first. If the effect of rest or physical fatigue is the same each day, then these per cents would be the same. The average and mean variation is therefore legitimate in this case.

In the association test it is necessary to compare the results obtained on the various days. For this reason the conditions on the various days was kept as nearly uniform as possible.

The average time of recall for each day is given in Table IV*a*, but instead of giving the mean variation, the number of responses that required more than 10,000 σ or less than 3000 σ are given in Table IV*b*. The averages in this table were obtained from the total number of individual responses, while the final averages in Table IV*a* were obtained by taking the average of each day's average.

In case any one should wish to make a more careful study of the results than these tables permit, a complete duplicate copy of all the results used in compiling these tables may be procured from the general library of the University of Michigan or the University of Kansas.

RESULTS.

TABLE I*a*.—ADDITION TESTS. Average number of problems, and per cent correct, from total daily records given in five-minute periods. (For number of cases, see Table I*b*.)

Subj.	Interval.	Test.	First 5 min.		Second 5 min.		Third 5 min.		Total.	
			No.	% Cor.	No.	% Cor.	No.	% Cor.	No.	%Cor.
Ca.	Rest 15 min.....	1	7.1	83.8	8.8	55.2	7.5	76.9	24.3	69.6
		2	8.4	90	9.5	56.4	9.3	36.8	27.8	66.4
	5½ kg. 7½ min.....	1	8.6	74.4	8.4	35.9	9.6	59.3	26.6	59.2
		2	9.3	67.7	8.4	82.2	8.3	90	26	67.4
Da.	Rest 15 min.....	1	11.7	83.7	10.9	72.3	9.7	81.4	32.4	77.4
		2	12	76.8	11.2	58.4	11	75.8	44.3	71
	5 kg. 10 min.....	1	10.9	60.8	10.3	51.4	11.9	71.2	33.1	61.1
		2	12	60.3	10.7	81.9	13.1	71.7	36	70.7
	10 kg. 10 min.....	1	12.7	80.5	11.5	88.6	11.9	75 2	36.1	80.4
		2	13.1	82.	12.1	81.4	11.2	69.7	36.5	78.8
Ba.	Rest 15 min.....	1	8.1	78.7	7.8	71.9	8	89.6	24	79.9
		2	8.7	67.4	7.4	73.8	7.4	96.4	24.2	74.8
	5 kg. 10 min.....	1	7.5	77.9	6.5	79.6	6.9	82.4	20.9	79.6
		2	7.9	74.6	7.1	77	7.5	70.7	25	73.8
	9 laps, 167 sec.....	1	10.3	83.9	8.8	88.6	8.9	88.8	28	87.1
		2	8.9	76.7	8.1	87.5	8.5	80.1	25.5	81.4
	18 laps, 360 sec.....	1	10.5	80.9	9.7	84.8	9.3	94.1	29.5	86.6
		2	8.5	95	9.3	73.5	9	89	36.8	85.8
	27 laps, 567 sec.....	1	9.5	88.4	9	90.6	9.5	88.5	28	91.2
		2	10.5	94.8	9.7	80.8	9.3	88.9	29.5	88.1

TABLE Ib.—ADDITION TESTS. Total results from each day's record and the per cent of increase or decrease in the second test. The first test is considered 100%.

	1st Test.			2d Test.		% of Inc. or Dec.	
Subj.	No.	% Cor.	Interval.	No.	% Cor.	No.	% Cor.
Ca.	19.5	52.6	Rest 15 min.....	23.5	65.9	120.5	125.3
	27.5	85.7	" " "	30	63.3	109.1	75
	27	70.4	" " "	30	70	111.1	99.4
						Av. 113.6	99.9
						m.v. 4.9	16.9
	25	54.2	5½ kg. 5 min.....	24	83.3	96	153.7
	23	34.8	5½ " 7½ min.....	24	39	104.3	112.1
	32	87.5	5½ " 10 min.....	30	80	93.7	91.4
						Av. 98	119
						m.v. 4.2	23
Da.	36.3	77.9	Rest 15 min.....	37.4	83.9	103.1	107.7
	24.4	68.5	" " "	31.5	46	129.1	67.2
	35.5	85.9	" " "	34	83.3	95.8	97
						Av. 103.9	90.6
						m.v. 13.1	15.6
	27.6	65.2	5 kg. 10 min.....	30.4	66.9	110.2	102.6
	39	57.9	5 " 10 "	37.7	60.2	96.7	104
	32.7	60.2	5 " 10 "	40	75	122.3	124.6
						Av. 109.7	110.4
						m.v. 8.7	9.5
Ba.	17.8	67.4	Rest 15 min.....	19	78.4	106.7	116.3
	22	77.3	" " "	25	64	113.7	82.8
	27	88.8	" " "	28	80.7	103.7	90.9
	29.3	86.3	" " "	25	76	85.3	88.1
						Av. 102.4	94.5
						m.v. 9	10.9
	24	70.8	5 kg. 7½ min.....	21	42.9	87.5	60.6
	20.4	83.3	5 " 10 "	25	88	122.5	105.6
	21.1	81.9	5 " 10 "	25	88	113.1	107.4
	17	82.3	5 " 15 "	21	76.2	123.5	92.6
						Av. 111.5	91.6
						m.v. 12.2	15.5
	28.6	89.5	9 laps, 165 sec.....	26	80.8	91	90.3
	28.7	87.3	9 " 167 "	26.1	83.9	99.4	96.1
	27.6	85.5	9 " 166 "	25	84	90.6	98.2
	28.4	86.1	9 " 165 "	24.8	77.5	87.3	90
						Av. 92.6	93.7
						m.v. 3.9	3.5
	29	82.7	18 laps, 360 sec.....	26	84.6	89.6	102.3
	29	85.4	18 " 359 "	26.4	84.7	91	99.2
	30	90	18 " 360 "	28	85.7	93.3	95.2
	30.2	88.2	18 " 360 "	26.9	86.6	89.1	98.4
						Av. 90.8	98.8
						m.v. 1.4	2
	28	93.1	27 laps, 570 sec.....	29	89.7	103.6	96.3
	28	89.3	27 " 566 "	30.5	90.1	108.9	100.6
	27.9	88.5	27 " 568 "	29.6	86.6	100.6	97.8
	29.4	88.3	27 " 565 "	29.3	90.6	99.7	102.6
						Av. 103.2	99.3
						m.v. 3.1	2.3

TABLE II*a*.—MULTIPLICATION TESTS. Average number of problems, and per cent correct, from total daily records given in five-minute periods. (For number of cases, see Table II*b*.)

Subj.	Interval.	Test.	First 5 min.		Second 5 min.		Third 5 min.		Total.	
			No.	% Cor.	No.	% Cor.	No.	% Cor.	No.	%Cor.
Co.	Rest 20 min.....	1	7.9	57.1	7.5	65.1	7.2	69.4	22.9	68.2
		2	7.5	47.7	8.5	66.6	8.5	73.3	24.1	59.4
	Thumb 20 min.....	1	11.1	76.3	11.1	64.3	9.9	63.4	32.1	67.4
		2	11.7	68.7	11.4	66	11.1	68.9	34.8	68.6
	Body 20 min.....	1	11.8	70.5	11.5	49	11.1	58.6	34.5	61.3
		2	12.2	63	10.8	69.4	12.2	47.2	34.7	61.4
De.	Rest 20 min.....	1	15	75.8	14.9	84.8	15.2	74.3	45.2	78.8
		2	15.1	77.5	14.4	57.1	14.7	66.2	54.1	67.2
	Thumb 20 min.....	1	17.3	84.1	17.4	84.6	16.1	77	50.9	82.1
		2	17.4	80.9	17.4	84.3	17.3	70.8	52.1	78.6
	Body 20 min.....	1	15.9	73.6	16.2	84.4	16.6	84.9	48.3	80.9
		2	16.5	73.7	16.9	80.3	17	81.6	51.2	78.1
Ba.	Rest 15 min.....	1	5.6	66.7	5.4	63.4	5.6	72	16.7	70.7
		2	4.8	54.2	5.3	60.1	4.4	62.5	14.6	58.5
	18 laps, 347 sec.....	1	5.5	56.2	6.4	74.7	4.6	69.2	16.5	63.4
		2	5.1	54.6	4.5	45.3	4.8	71.6	14.4	57.1
	27 laps, 572 sec.....	1	5.3	54.2	5.2	43.3	5.8	73	16.3	57.1
		2	5.8	62.6	5.6	71.6	5.9	53.7	17.4	61.3
	36 laps, 819 sec.....	1	5.1	81	5.2	69	4.5	24.7	14.8	58.2
		2	4.9	90.4	4.5	82.1	4.8	60	14.2	77.5
	1½ mi. 610 sec.....	1	6.9	78.2	6.3	72.2	5.7	62.8	18.9	72.1
		2	6.9	79.7	6.2	66.5	5.7	68.2	19.8	72.5

TABLE II*b*.—MULTIPLICATION TESTS. Total results from each day's record, and the per cent of increase or decrease in the second test. The first test is considered 100%.

	1st Test.			2d Test.		% of Inc. or Dec.	
Subj.	No.	% Cor.	Interval.	No.	% Cor.	No.	% Cor.
Co.	21.4	57.9	Rest 20 min.	23.4	55	109.3	94.9
	21	76.2	" " "	24.5	36.7	116.6	48.2
	22.7	60.3	" " "	21.4	71.9	94.3	119.2
	26.5	48.5	" " "	27	74.1	101.9	152.8
					Av.	105.5	103.8
					m.v.	4.9	32.2
	30.8	70.8	Thumb 20 min.	31	74.2	100.3	104.8
	27.5	56.4	" " "	30	76.6	109.1	118.1
	34.3	64.1	" " "	39.4	56.9	114.9	88.7
	35.8	78.2	" " "	39	66.6	108.9	85.2
					Av.	108.3	99.2
					m.v.	4	12.2
	29.7	60.6	Body 20 min.	29	51.7	94.3	85.3
	32.7	63.2	" " "	31	67.7	94.9	107.1
	37.6	58.5	" " "	38	60.5	101.1	103.4
	38	63.1	" " "	41	65.8	107.9	104.3
					Av.	99.5	100
					m.v.	4.7	8.6
De.	37	89.2	Rest 20 min.	40	52.5	108.1	58.9
	45	71.1	" " "	46	69.5	102.2	97.9
	52.6	82.8	" " "	47	65.9	89.3	79.6
	46.2	72	" " "	43.5	81.1	94.1	112.7
					Av.	98.4	87.5
					m.v.	6.9	18
	51	90.2	Thumb 20 min.	44	84.1	86.5	93.2
	48.5	78.5	" " "	51	74.5	105.1	94.9
	54.5	77.9	" " "	54	77.7	97.4	99.7
	49.5	81.8	" " "	59.3	78.1	119.8	95.5
					Av.	102.2	95.8
					m.v.	10.2	1.9
	42	85.7	Body 20 min.	44	81.8	104.7	96.6
	47.6	76.9	" " "	54	74	113.4	99.1
	53.7	83.2	" " "	52.7	73.4	98.1	100.1
	50	78	" " "	54	83.3	108	106.9
					Av.	106.1	100.7
					m.v.	3.5	3.1
Do.	17	64.7	Rest 18 min.	16.5	54.5	97.1	84.2
	22.3	55.1	" 15 "	24	75	107.6	136.1
	25.3	64.4	" " "	26.3	73.3	103.9	113.8
	21.3	57.7	" " "	23	73.9	107.9	128.1
	25.5	74.5	" " "	26	80.8	101.9	108.4
					Av.	103.7	115.1
					m.v.	3.3	14.6
	25	56	5 kg. 10 min.	27.5	81.8	110	144.6
	25	76	5 " 10 "	24	87.5	96	115.1
	19.5	64.1	5 " 11 "	20.3	55.6	104.1	86.7
	23.3	61.3	5 " 10 "	24.5	75.5	105.1	123.1
	20.3	70.4	5 " 10 "	26.3	64.8	129.5	92
					Av.	108.9	112.3
					m.v.	8.6	18.4

TABLE IIb—Concluded.

Subj.	1st Test. No.	1st Test. % Cor.	Interval.	2d Test. No.	2d Test. % Cor.	% of Inc. or Dec. No.	% of Inc. or Dec. % Cor
	23.3	61.3	5 kg. 20 min.....	24	58.3	103	95.1
	21.5	76.7	5 " 20 "	26	76.9	120.9	100.1
	26.5	79.2	5 " 20 "	26.5	56.6	100	71.4
	22.3	87.4	5 " 20 "	24.3	75.3	108.9	86.1
	24.5	83.6	5 " 20 "	26	57.7	106.1	69
						Av. 107.8	84.3
						m.v. 6.4	9.3
Ba.	14	42.9	Rest 15 min.....	16.4	57.3	117.1	133.6
	14.1	78.7	" " "	13.4	59.7	95	74.6
	19.5	79.4	" " "	12.7	39.3	65.1	49.5
	16.4	67	" " "	12.1	57.8	73.7	86.3
	17.7	83	" " "	15.2	59.2	85.9	71.3
	18.5	73.5	" " "	18	77.7	97.3	105.7
						Av. 89	86.8
						m.v. 14.1	22
	15.1	59.6	18 laps, 347 sec.....	14.5	62	96	104
	18	72.7	18 " 345 "	15.2	40.7	84.4	55.5
	16.3	70	18 " 348 "	13.5	62	82.8	88.5
						Av. 87.7	82.8
						m.v. 5.5	17.9
	15.3	28.1	27 laps, 572 sec.....	13.5	40.7	88.2	141.2
	17.3	63.5	27 " 574 "	20	70	115.3	110.2
	16.3	79.8	27 " 571 "	18.6	73.2	114.1	91.7
						Av. 105.9	114.3
						m.v. 11.8	14.5
	14.1	64	36 laps, 819 sec.....	13.8	73.5	90.8	114.9
	13.8	57.2	36 " 818 "	12.7	100	92	174.8
	16	62.5	36 " 820 "	16	62.5	100	100
	15.4	54.2	36 " 819 "	14.6	84.6	94.8	156.1
						Av. 94.4	136.5
						m.v. 2.7	29
	16.3	75.4	1½ miles, 610 sec.....	16.3	61.4	100	81.4
	19.7	45.6	1½ " 540 "	17.1	76	86.8	166.6
	22.6	76.8	1½ " 710 "	20	65	88.5	84.6
	19	78.9	1½ " 710 "	19.3	79.2	101.5	100.4
	19	94.7	1½ " 620 "	20.4	85.3	107.4	90.1
	18.2	61.5	1½ " 660 "	20.5	68.3	112.6	111
						Av. 97.8	105.7
						m.v. 8.4	22.1

TABLE III*a*.—SOUNDER TESTS. Averages from total daily records

Subj.	Interval.	Test.	First four minutes.					Second four minutes.				
			Sounds.	Omissions.	Errors.	% of Omissions.	% of Errors.	Sounds.	Omissions.	Errors.	% of Omissions.	% of Errors.
Bt.	Rest 20 min.	1	61.3	26.3	15.5	42.5	25.7	61	22.2	10.8	35.9	17.6
		2	69.5	13.5	7.8	22	18.4	52.7	16	10.1	27.5	19.6
	Harness 20 min.	1	63.8	28.4	15.4	44.4	24.4	61.2	25	11.4	40 2	18.2
		2	62	20.8	8.4	34.3	13.8	58.8	17	9.6	28.8	16.5
De.	Rest 20 min.	1	62.7	21	7.6	33.4	11.8	60.1	15.7	7.3	25 2	12.1
		2	60.8	15.4	6.1	26.7	9.8	56.6	12.8	4.6	27.5	8
	Harness 20 min.	1	58.4	16.6	8.4	28.2	14.6	56.7	15.7	11.7	17.9	21
		2	57.4	13	7.1	22.6	12.7	22.6	12.7	6.7	13.4	10.2
W.	Rest 20 min.	1	60.3	22.6	15.5	37.5	25.7	60.3	20.8	12.2	34.5	20.2
		2	59.5	16.6	8	27.9	13.4	59.7	16.9	12.4	28.3	20.8
	Harness 20 min.	1	58.8	19.6	13.2	33.3	22.5	59.7	19.8	13.9	33.2	23.3
		2	60	15.1	8.1	25.2	13.5	56.9	16.2	12.6	28.5	22.1
Be.	Rest 20 min.	1	61	9	18.6	14.7	30.5	59.2	11.4	17.4	19.2	29.2
		2	62	5	6	8.1	9.7	60.4	6.4	9.2	10.6	15.2
	Harness 20 min.	1	63.4	6.2	15.8	9.8	24.9	61.8	6.8	9.6	11	15.5
		2	63	6.4	8.2	10.1	13	60.2	7.4	12.4	12 3	20.6
Bu.	Rest 20 min.	1	62.8	5.8	17	9.2	27.1	63.4	7	19.8	11	31.2
		2	62.6	6.6	13	10.5	20.8	59.6	5.4	10.6	9.1	17.7
	Harness 20 min	1	62.6	6	13.2	9.6	21.1	58.6	4	13.4	6 8	22.9
		2	62.2	7.8	11.4	12.5	18.3	58.8	4.8	9.2	8 3	15.6
Do.	Rest 20 min.	1	63.7	15.5	19.5	24.3	30.6	64.5	18	22	27.9	34.1
		2	58.5	11.7	12.5	20	21.4	61.5	6.7	12.5	10.9	20.3
	Harness 20 min	1	60.2	9.5	16.7	15.8	27.7	62	14	19.5	22.6	31.4
		2	64	14.5	25.2	22.7	39.3	60.5	16.7	23.2	27.6	38.3
	Rest 2 hours	1	72.7	7.5	7.2	10.3	10	81.2	13 2	18.5	16.3	22.8
		2	81.7	12.2	16.2	15	19.8	85	13.2	16.2	15.6	19.1
	Walk 2-3 hours.	1	68	7.2	11.7	10.7	17.3	72	14.7	15.7	20.5	21.9
		2	71	10.2	12	14.4	16.9	76.5	17.7	28 7	23 2	37.6
S.	Rest 2 hours.	1	59.8	18.8	22	31.1	36.8	58.8	16.4	18.6	27.9	31.6
		2	58.2	6.8	15	11.7	22.3	60.8	10	15.2	16.5	24.9
	Walk 2-3 hours.	1	57 2	12.2	17.8	21.3	31.1	57.2	12.8	12.8	22 4	22.4
		2	60.6	13 3	15.6	21.8	25.7	60.4	20.2	20	33.4	33.2

given in four-minute periods. (For number of cases, see Table III*b*.

Third four minutes.					Fourth four minutes.					Total.				
Sounds	Omissions	Errors	% of Omissions	% of Errors	Sounds	Omissions	Errors	% of Omissions	% of Errors	Sounds	Omissions	Errors	% of Omissions	% of Errors
60	24.1	15.5	34.6	25.7	59	19.8	12.7	33.4	19.1	241.3	92.4	54.5	38.3	22.6
57.1	19.1	11.1	31.6	19.3	59.8	15	7.5	25.1	12.6	239.1	63.5	36.5	26.6	15.3
59.8	21.4	10.4	35.9	17.4	59.8	22	9.4	35.2	18.9	244.6	96.8	46.6	39.5	19.1
59	22	10.6	37.4	18.4	59.8	18.6	9.6	28.8	18.4	239.6	78.4	38.2	32.7	15.9
56.6	15.3	5.7	26 3	10	61.3	14	3.1	22.1	10.3	240.8	66	25.7	27.4	10.6
53.6	13.8	4	25	7.3	58	14.1	7	24.6	12.7	229.2	56.1	21.7	24.4	9.5
57.7	12.8	4.7	21.8	8	58	9.8	4	16.7	8.7	230.8	54.9	28.8	23.8	12.5
57.7	14.3	7.8	23.9	13.6	58.5	12.5	3.7	21.2	6.4	230.3	53.2	24.6	23.1	10.7
58.1	21.7	15.2	37.4	26.2	60.8	19.5	9.5	32.1	15.6	239.5	84.6	52.4	35.3	21.9
61.4	19.1	11.7	31.1	19.1	60 7	20.1	13.2	33.1	21.8	241.3	72.7	45.3	30.1	18.9
62	17.6	12.2	28.4	19.7	56.2	17.9	11.4	31.9	20.3	236.7	74.9	50.7	31.6	21.4
59	19	10.7	32.2	18.1	57.1	19.7	11.7	34.5	20.5	233	70	43.1	30	18.5
62.2	12.4	17.8	19.9	28.6	57.4	6.8	13	11.8	22.6	239.8	39.6	66.8	12.3	27.9
58.4	5.6	8.2	9.6	14	60.6	4.6	7.4	7.5	12.2	241.4	21.6	30.8	8.9	12.7
61.2	8.8	14	14.4	22.8	61.8	4.6	9.4	7.4	15.2	248.2	26.4	48.8	10.6	19.7
60.2	8	10.2	13.1	16.9	60.4	10.1	17.4	16.7	28.8	243.8	31.9	48.2	13.1	19.7
60.6	4.2	12.2	6.9	20.1	60.4	6.4	10.2	10.6	16.8	247.2	23.4	59.2	9.5	23.9
60	4.6	10.6	7.7	17.6	59.8	4.8	10.6	8	17.7	242	21.4	44.8	8.8	18.5
60	6.2	19.4	10.3	32.3	58.6	5.4	13	9.2	22.2	239.8	21.6	59	9	24.6
59.6	7.6	13.4	12.7	22.5	60	12	15.2	20	25.3	240.6	32.2	49.2	13.4	20.4
63.5	16.5	22.5	25.9	35.4	62.5	14.5	20.7	23.2	33.1	254.2	64.5	84.7	25.4	33.3
60.5	9.2	14	15.2	23.1	61	18.5	25.2	30.3	41.3	241.5	46.1	64.2	19.1	26.6
59.7	13.2	15.2	22.1	25.4	63.5	16.2	27.2	25.5	42.8	245.4	52.9	78.6	21.1	32
61.5	12.2	21.2	19.8	34.5	61.5	10.2	19	16.7	31.4	247.5	53.6	88.6	21.7	35.8
82	13.5	15.7	16.5	19.2	81.5	20.2	20.7	24.8	25.5	317.4	54.4	62.1	17.1	19.5
87.2	18	17	20.6	19.5	92.2	15.7	14.5	17	15.4	346.1	59.1	63.9	17.1	18.4
74.2	14.7	18	19.9	24.2	72.2	14.5	17.2	20.1	23.9	286.4	51.1	62.6	17 8	21.9
77	7.5	15.2	9.7	19.8	86.2	19	24.7	22	28.7	310.7	54.4	80.6	17.5	25.9
57	18.6	15.2	32.6	23.2	63	19.8	19.8	31.5	31.4	238.6	73.6	75.6	30.8	31.7
59.4	14.6	14.2	21.2	23.9	55.4	14	15.8	25.3	28.5	233.8	45.4	60.2	18.9	25.7
57.8	15.8	11	27.3	19	59.2	14.6	10.8	24.7	18.2	231.4	55.4	52.4	23.9	22.6
59.8	14.6	15.4	24.4	22.4	59.4	17.4	15.6	29.3	22.6	240.2	65.4	66.6	27.2	27.7

TABLE III*b*.—SOUNDER TESTS. The per cent of total omissions and errors from daily records, and the per cent of increase or decrease in the second test. The first test is considered 100%.

	1st Test.			2d Test.		% of Inc. or Dec.	
Subj.	% O.	% E.		% O.	% E.	% O.	% E.
Bt.	38.4	38.9	Rest 20 min.....	37.8	39.6	98.4	101.8
	29.9	20.1	" " "	18.4	6.6	61.5	32.8
	54.5	33.2	" " "	27.2	14.3	49.9	43.1
	38.6	14.9	" " "	36.5	12.3	94.5	82.5
	33.7	11.5	" " "	31.9	15.7	94.6	136.5
	26.9	13	" " "	14.5	8.1	53.9	62.3
					Av.	74.6	73.5
					m.v.	20	30.4
	24.9	15.4	Harness* 20 min.....	23.8	18	95.5	116.8
	50.4	28.6	" " "	45	16.4	89.2	57.3
	43.5	19.6	" " "	31.9	11.4	73.3	58.1
	42.5	22.8	" " "	35.7	16.1	84	72.8
	35.2	12.7	" " "	32.9	17.6	93.4	138.5
					Av.	86.2	80.8
					m.v.	6.9	29.6
De.	12.9	7.6	Rest 20 min.....	9	7.6	69.7	68.4
	51.6	17.4	" " "	43.7	16.7	84.6	95.9
	39.2	10.2	" " "	26.9	6.4	68.6	62.7
	30.1	10.8	" " "	29.3	15.5	97.3	143.5
	12	3.4	" " "	18.7	5.5	115.8	161.7
	21.2	9.1	" " "	16.9	44.9	79.7	54.9
	20.8	15.4	" " "	24.2	11.2	116.8	72.7
					Av.	89.5	87.7
					m.v.	16.7	32.8
	27.3	16.4	Harness 20 min.....	7.4	5.6	42.7	34.1
	31.5	19.6	" " "	28.1	18.3	89.2	93.3
	31.2	9.6	" " "	33.9	13.3	108.6	138.5
	29.5	18.9	" " "	40.2	13.8	136.6	73
	14.8	7.1	" " "	10.7	4.3	72.3	60.5
	14.7	6.9	" " "	15.5	7.5	105.4	108.7
	27.1	8.5	" " "	28.8	11.2	106.2	131.7
					Av.	99.1	85.1
					m.v.	26.2	31.3
W.	31.7	24.2	Rest 20 min.....	36.1	20.3	113.8	83.8
	23.7	23.9	" " "	27.4	15.6	119.1	65.2
	53.7	34.1	" " "	34.4	25.8	64	75.6
	47.6	24.4	" " "	51.7	37.1	108.6	152
	37.1	16.7	" " "	37	12.6	99.7	75.4
	30.8	16.2	" " "	24.7	17.4	80.1	107.4
	36.4	26.7	" " "	29.5	17.1	81	64
	33.7	16.6	" " "	14.6	5.9	43.3	35.5
	28.9	26.9	" " "	21.4	15.4	74	57.2
	28.6	9.8	" " "	26.5	9.8	76.5	100
					Av.	82.1	80.5
					m.v.	18.7	22.1

* Lifting body ergograph with harness.

TABLE III*b*—CONTINUED.

Subj.	1st Test. % O.	1st Test. % E.		2d Test. % O.	2d Test. % E.	% of Inc. or Dec. % O.	% of Inc. or Dec. % E.
W.	34.9	20.9	Harness 20 min.....	29.1	18.4	83.3	88
	26.7	24.5	" " "	20.8	18.2	77.9	74.6
	17.3	15	" " "	22	16.7	127.1	111.3
	51.1	32.4	" " "	44.4	16.1	86.8	49.7
	31.4	20.1	" " "	31.6	17.3	100.6	86
	42.6	26.6	" " "	39.4	18.7	92.4	70.3
	32.9	17.7	" " "	31.5	19.9	95.7	112.4
	24.4	14.8	" " "	26.3	9.6	107.7	64.8
	35.8	14.1	" " "	29.1	17.1	81.2	128.3
	20.3	15.2	" " "	23.9	13.4	117.7	88.1
					Av.	94	82.1
					m.v.	12.7	19.1
Be.	11.8	31.3	Rest 20 min.....	12.3	18.1	104.2	57.8
	26.4	38	" " "	13.8	12.5	52.3	32.9
	14.9	21.1	" " "	10.1	13.2	67.8	62.5
	9.6	13.1	" " "	4.3	8.6	44.7	65.6
	19.7	35.1	" " "	4	10	20.3	28.5
					Av.	57.9	49.5
					m.v.	20.5	13
	10.4	18.8	Body 20 min.....	16.8	26.4	161.5	140.4
	7.9	20.2	" " "	13.9	23.7	175.9	117.6
	10.5	17.2	" " "	9.1	17.4	86.6	101.2
	15.5	27.4	" " "	18.1	24.7	116.8	90.1
	9.2	14.6	" " "	7.6	6.8	82.6	46.4
					Av.	124.7	99.1
					m.v.	35.2	24.7
Bu.	4.9	29.8	Rest 20 min.....	8	21.5	163.3	72.1
	7.3	29.3	" " "	12.3	24.1	141.1	82.2
	6.1	9.6	" " "	.4	2.9	6.6	30.2
	23.7	43.1	" " "	20.7	34.8	87.3	80.7
	4.7	6.9	" " "	3	6.9	43.5	100
					Av.	88.4	73.2
					m.v.	51.1	17.5
	10	13.9	Harness 20 min.....	14.7	11.8	114	84.9
	5.9	47.1	" " "	8.6	18.2	145.7	59.7
	2.4	14.5	" " "	.8	7.2	33.3	49.6
	16.2	35.2	" " "	24.9	40.1	153.7	113.9
	10.7	11.5	" " "	17.6	12.6	164.5	109.6
					Av.	128.4	83.5
					m.v.	38.7	23.1
Do.	37.5	38.6	Rest 20 min.....	21.6	30.3	57.6	78.4
	7.7	8.1	" " "	9.9	6.3	128.5	77.7
	23.6	35.6	" " "	15.7	21.8	66.5	61.2
	32.9	51.2	" " "	30.3	50	91.8	97.6
					Av.	86.1	78.7
					m.v.	23.8	6.9
	20.6	25.7	Harness 20 min.....	18.8	28.5	91.2	110.9
	23.8	31.3	" " "	24.4	47.6	106.7	152.1
	29.3	56.6	" " "	18.4	42.9	62.8	75.8
	11.5	17.9	" " "	15	20.3	130.4	113.4
					Av.	97.8	113.1
					m.v.	20.9	19.7

TABLE IIIb—Concluded.

Subj.	1st Test. % O.	1st Test. % E.		2d Test. % O.	2d Test. % E.	% of Inc. or Dec. % O.	% of Inc. or Dec. % E.
Do.	13.1	14.3	Rest 2 hours.....	16.6	14.8	126.7	103.5
	15.6	17.2	" " "	9.8	22.7	62.8	131.9
	26.9	31.3	" " "	30.4	23.1	113	73.4
	11.7	10.7	" " "	7.6	17.4	64.9	162.6
						Av. 95.8	105.9
						m.v. 28	29.4
	13.8	38.4	Walk 2 hours.....	13.1	29.1	94.9	75.7
	17.2	25	" 2 "	17.9	30.3	104	120.1
	31.5	25.4	" 2¼ "	34.9	39.5	110.7	159.8
	9	4.3	" 3 "	6.2	7.4	68.9	172
						Av. 100.5	114.1
						m.v. 12.7	37
S.	34	35.1	Rest 2 hours.....	22.2	36.7	65.3	104.5
	28	23.2	" " "	13.6	8	48.6	34.5
	28.8	34.5	" " "	26	32	90.2	92.7
	33.9	34.9	" " "	14.5	20.9	42.7	59.8
	26.4	26.9	" " "	16.1	27	60.9	100.3
						Av. 61.2	87.8
						m.v. 12.9	23.1
	27.7	20.5	Walk 2 hours.....	21.4	22.7	77.2	110.7
	23.8	21.7	" 2 "	36.6	33.6	153.3	154.4
	20.7	14.5	" 2½ "	21.9	19	105.3	131
	16.9	20.9	" 2¼ "	28.8	31.8	170.4	152.1
	34.7	39.2	" 2 "	27.7	23.8	79.8	60.7
						Av. 110.5	111.9
						m.v. 32.5	31

TABLE IV*a*.—ASSOCIATION TESTS. The per cent correct and the average time of the daily records, and the per cent of increase or decrease when the learning followed physical fatigue. The corresponding records when learning followed rest are considered 100%.

Subj.		After Rest. % Cor.	After Rest. Av. Time.	After Harness. % Cor.	After Harness. Av. Time.	% of Inc. or Dec. % Cor.	% of Inc. or Dec. Av. Time.
R.		82	10893	47.6	3588	58	39.2
		78.6	6772	67.9	8237	86.4	121.6
		60.7	4977	50	6308	82.3	126.8
		67.9	5757	35.7	13004	52.6	224.1
		82.1	7741	35.7	4234	43.4	54.7
		60.7	5000	64.3	11857	105.9	237.1
		71.4	4584	28.6	14001	40.1	305.4
	Av.	71.9	6532	47.1	8747	66.9	157.5
	m.v.	7.7	1660	11.8	3606	21.1	81.1
M.		71.4	1485	57.1	4024	79.9	270.9
		92.9	2305	89.3	3766	96.1	163.3
		82.1	3476	60.7	3488	72.7	100.3
		82.1	1897	71.4	3317	86.9	174.9
		96.4	3717	92.9	3328	96.4	89.5
	Av.	84.8	2576	74.3	3585	86.4	159.8
	m.v.	7.7	816	13.5	258	8.1	51.9
Br.		55	7039	40	7026	72.7	99.8
		70	7691	65	9008	92.8	117.1
		72	10399	60	8161	83.3	78.4
		75	6712	61	6597	81.3	98.3
		62.5	6595	45	10141	72	153.9
	Av.	66.9	7687	54.2	9986	79.4	109.5
	m.v.	6.5	1086	9.4	1861	6.7	50.8
				(After Running 2 Miles.)			
E.		35	3500	70	5520	200	157.7
		32.2	5726	75	7692	232.9	134.3
		65	6175	40	3819	61.5	61.8
		25	6829	20	1314	80	19.2
	Av.	39.3	5557	51.2	4588	143.6	93.2
	m.v.	12.8	1029	21.2	2019	72.8	52.7
				(After Walking 2½ Hours.)			
H.		20	2824	25	7463	125	260.7
		40	2940	37.5	14012	93.7	476.6
		35	5412	83.3	6997	237.1	129.3
		55	5047	72.2	4315	131.3	85.5
		45	4624	44.4	5633	98.6	121.8
	Av.	39	4169	52.1	7326	137.1	214.8
	m.v.	9.2	1030	20.1	2751	39.9	123.1
Do.		40	3453	15	7519	37.5	217.7
		70	4609	50	3093	71.4	67.1
		40	8267	45	6315	112.5	76.4
		81.2	5973	25	5505	30.8	92.1
		40	9282	45	6311	112.5	67.9
	Av.	53.5	6292	32.5	5645	66.2	99.9
	m.v.	14.7	1680	14.1	1068	33	39.3

TABLE IV*b*.—ASSOCIATION TESTS. The average association times taken from the total individual results, and the distribution of extremely long and short times.

Subj.	R.	M.	Br.	E.	H.	Do.
After rest. Per cent correct,	71.9	80.7	67.	47.	40.6	54.4
Average time	5931	2765	7426	4706	4449	5966
No. of cases	74	59	34	15	24	34
No. $> 10{,}000\sigma$	13	2	5	2	3	8
No. $< 3{,}000\sigma$	23	41	5	4	7	11
After fatigue. Per cent correct,	47.1	70.2	54.2	51.2	50.9	35.4
Average time	9488	3159	6151	5595	7172	5442
No. of cases	42	52	30	22	35	23
No. $> 10{,}000\sigma$	9	2	7	4	6	4
No. $< 3{,}000\sigma$	7	32	8	13	8	11

DISCUSSION OF RESULTS.

The consideration of results that deal in any way with physical fatigue is certain to raise the question as to how much physical fatigue, general or special, has been produced in a given individual by the method used. This it must be confessed is a difficult question to answer in any case, and particularly so in the present set of experiments where mental tests were to be given which must not be disturbed more than is necessary. For this reason, and also because of the difficulty of analyzing the chemical products of fatigue, the attempt to determine the physical fatigue by measuring these products was abandoned. Furthermore, it is doubtful whether a very definite evaluation of the degree of fatigue could be secured in this way. The only remaining possibility seemed to be to test the physical capacity before and after the work period, and compare the results with those obtained before and after an equal rest interval. For this purpose a large dynamometer was used. This instrument was similar to the ordinary hand dynamometer, only much larger, and was fastened to the floor by means of a chain attached to one end of the spring. A wooden handle was attached to the other end of the spring. The subject exerted himself in as nearly as possible the same position as was required at the beginning of the lift with the wall machine. The result was disappointing. The subject, either because he shifted his position slightly, or because for a single pull he exerted more effort, was able to exert as much or more force on the dynamometer after he had worked at the wall machine. For example, Ca. was able to lift 100 kilograms before the work

period. At the end of seven and one-half minutes of lifting a weight of 5½ kilograms he was forced to stop from exhaustion. Yet he then lifted 110 kilograms. This method was, therefore, abandoned, and the general habits and physical development of each subject were used as a basis upon which to approximate the value of a given amount of work for the production of fatigue in each individual.

The form of the ergographic curves obtained with the two spring ergographs may, to some extent, indicate the degree of fatigue, though these curves do not, as a rule, resemble very closely the form of such curves as we find them in the literature. There was always a quite rapid fall in the height of the curve during the first three minutes, and by the end of five minutes it had reached a level that was generally maintained until the end. The principal exceptions were the curves of W., which decreased rapidly during the first three minutes and then more and more gradually to the end. At the end of the twenty minutes his curves were still decreasing. Whether the knowledge that the work was expected to endure for twenty minutes compelled the subjects unconsciously to conserve their strength, or whether the realization that the curve was falling acted as an incentive (the curves were not screened from the subject) to exert more effort, as Wright (47) found, or whether the employment of a large group of muscles allowed sufficient shifting of the burden to alter the form of the curve, our work furnishes no data to determine. It is quite probable that more than one of these factors had an influence. Both ergographs gave the same form of curves and both were open to these possibilities, though the possibility of shifting with the thumb ergograph was not so great as with the lifting ergograph.

ADDITION TEST.

With Ca. speed in adding has always been increased after rest and decreased two out of three times after physical work. Two factors might influence accuracy: an increase (or decrease) in speed might mean a corresponding decrease (or increase) in attention to accuracy of the processes; or it might mean greater or less mental ability expressed in terms of accuracy of the association processes independently of the association time. The subjects were always instructed to add as rapidly as was consistent with accuracy, and it was ex-

pected that attention would be about equally divided between speed and accuracy. The emphasis was not to be placed on either phase of the test to the exclusion of the other. We might, therefore, assume that this sort of variation would be slight, except as it was brought about by the fatigue. We are left with the conclusion that for Ca. physical fatigue tended to decrease speed and to increase accuracy. That Ca. was physically fatigued was quite certain. As has been mentioned, he was not a physically strong man, and he worked faithfully.

Similar fluctuations are evidenced in the results of the other two subjects. Da. nearly always showed increased efficiency in the second test, whether it is after rest or physical work. His greatest increase is in speed after rest, but this is partially counterbalanced by a decrease in accuracy. With an increase in the duration of the physical work or an increase in the weight to be lifted his speed decreases and accuracy increases, very much as in the case of Ca. On the other hand, Ba. is inclined to show a decrease in both speed and accuracy after both rest and physical work, though this is not always the case. After lifting a light weight ten minutes speed is increased, while accuracy is about the same as after rest. The nine-lap and eighteen-lap runs are quite uniformly followed by decreases in speed and accuracy, on the whole, a little below the decreases manifested after the rest periods; but the twenty-seven-lap runs effect an increase in speed, and an increase in accuracy half the time, though the average of the four tests gives a decrease. While these differences for Ba. are slight, they are quite constant. Certainly the weight of five kilograms could not be considered very fatiguing for Da. and Ba. With the heavier weight Da. seemed fatigued, though not what could be considered exhausted. Running on the indoor track was only slightly fatiguing for Ba. at the end of nine laps; he "felt tired" at the end of eighteen laps (one mile); and he thought twenty-seven laps was the limit of his endurance. Beyond thirty-six laps (in the next series) he would not attempt to run.

MULTIPLICATION TEST.

Ba. was the only subject to be used with both the addition and the multiplication tests. His results, therefore, form the connecting link between the two tests for a basis of compari-

son. If we examine Tables I*b* and II*b*, we find that after rest he shows a decidedly greater decrease in both speed and accuracy with the multiplication tests than with the addition test. As multiplication is a much more difficult process than addition as the two were employed, we may assume that the mental fatigue induced by the first test has not entirely disappeared at the end of the twenty-minute rest interval, or that his interest is not so great. It is true that the five-minute periods of the first tests, as given in Table II*a*, do no indicate any accumulation of fatigue, but this may be obscured by practice effects or overcome by inertia effects. The details of tables I*a*, II*a* and III*a* (pp. 213-222) will be discussed later. After eighteen laps he does better than after rest, but not so much better as in the addition test. After twenty-seven and thirty-six laps he shows marked improvement, though after thirty-six laps speed (on the average) has given way somewhat to an unusually large increase in accuracy. A large part of this variation is due to the test following the thirty-six laps on the second day of the series, though the general tendency for decreased speed and increased accuracy is seen throughout the series.

Just where in the total series the tests with the cross-country running should be considered to belong is difficult to determine. These runs were made over hills and uneven paths, usually in a strong wind. Ba. believed he was more fatigued than when he ran two miles (thirty-six laps) on the track, but other runners claimed that they always found it less fatiguing than the same distance indoors, providing they ran more slowly across country. Ba. in this series required considerably more time than he did indoors for the same distance. It was expected that the series would be completed by a series of five-mile runs across country, but a change in Ba.'s plans made it necessary to abandon this plan. It is necessary, therefore, to consider this series separately. The results would indicate that the fatigue was a little more than that produced by eighteen laps indoors.

In the tests with Co. and De. we have a different set of conditions. The time spent in physical work by these subjects was the same in each (twenty minutes), but the amount of physical fatigue produced was controlled by the type of work performed. A much smaller, isolated group of muscles

was used with the thumb ergograph than with the larger apparatus. It might be expected that if physical fatigue affects mental ability by virtue of the circulation of fatigue products from the working muscle, that the effect of the thumb ergograph would not be so great.

The influence of these two types of work is not very clear in the results obtained. The differences in speed and accuracy are not very great or constant. De. increases speed after rest twice and decreases it an equal number of times, but decreases accuracy three out of four times. In the two work series he has increased speed a little on the average, and increased accuracy slightly after the thumb exercise. Variations from day to day lead to little hope that any influence of physical fatigue can be recognized in his results. Even the big average increase in speed after rest is made in spite of two decreases out of four tests. An average of the per cent of increase or decrease in both speed and accuracy computed from Table II*b* gives 102.5 per cent after rest, 99 per cent after thumb exercise, and 101.2 per cent after body exercise. Neither De. nor Co. show the decrease in mental ability after twenty minutes' rest that is indicated by Ba.'s results. Co. has consistently increased speed after the thumb exercise, though accuracy is increased but twice and decreased an equal amount the other two times. He has not been able to produce an average increase after the body exercise, though he was as liable to increase as to decrease.

Just how fatigued either De. or Co. might have been would be difficult to estimate. Both were normally developed men, but they certainly found the work difficult. It is believed that each worked conscientiously. If he did so, he must have been greatly fatigued, in the arm when using the thumb ergograph, and more generally in the legs and shoulders when using the larger apparatus.

The results from Do. do not vary materially in speed. This may be due to the method employed. It will be remembered that he conducted the tests alone, and used a stop watch to determine the fifteen-minute period. The problems were also mimeographed on letter-size paper, in place of on numerous narrow slips as in the other experiments. Both of these variations when taken together might influence the subject's speed. Though the number of problems performed in a period

were not counted until the entire series was finished, a certain amount of space on the sheet might represent to the subject a certain amount of work done. This knowledge, coupled with the awareness that a certain amount of time had elapsed, might spur the subject to greater activity in case he were falling behind his usual amount. As the accuracy of the work was not determined until the entire series was finished, no more knowledge was possible in this case than the other subjects possessed regarding their accuracy.

Accuracy is distinctly improved in every instance after rest except in the first test. The recorded introspections show that the subject felt greatly fatigued from the first test of the first day, which the eighteen minutes of rest did not seem to relieve. This may account for the discrepancy of the first day's results. The lack of knowledge of the relation of the space covered to the amount of work done should also be considered a factor in this discrepancy. After lifting five kilograms ten minutes accuracy is improved nearly as much as after rest, but the variations are greater. After twenty minutes' lifting there is a notable decrease in accuracy with a relatively small variation from the average.

As was stated earlier, Do. could not have lifted the weight for twenty minutes at the beginning of the series. At least he thought he could not. The ten-minute periods seemed decidedly fatiguing even in the last test, though they never compared with the twenty-minute periods, which were extremely exhausting.

SOUNDER TEST.

This test differs from the addition and multiplication tests in an important respect. Speed as a variable factor in the subject's work is eliminated by the sounders being operated at a regular rate, which the subject must follow. This results in an incentive for the subject to keep sufficiently alert to discriminate the sounds as they are given in order to prevent absolute confusion. The accuracy of the discrimination alone, rather than the speed and accuracy of the association processes, is all that is measured. The speed of the subject's discrimination and reaction may be recorded by this method for a short series, but for a period of sixteen minutes it would be impracticable, as it would necessitate running the kymograph rapidly in order to record distinctly small units of time.

As the kymograph was run, the horizontal distances between the marks that indicated the sounders and the subject's reaction were only about one-fourth of an inch. Consequently little could be determined as to the subject's reaction time. A very long paper would be necessary in order to measure accurately the effect of fatigue upon the time of reaction to sounders.

It will be noticed that there is nearly always a decided increase in ability to discrinimate the sounds in the test following the rest periods for all subjects except for Do. in the case of the two-hour rests. The sounds were frequently slightly different on one day from what they were the previous day, but the principal factor seemed to be that the subjects seemed to forget the sounds from one day to the next, and the first test served as a means of relearning the relation of the four sounds. The results of Do. would bear out this assumption. As he operated the apparatus for all the other subjects, he was kept more familiar with the sounds the year he was subject with the two-hour rest periods, and consequently did not show improvement in the second test. During the year that Do. acted as subject with the twenty-minute rest periods the sounders were placed in one room with the subject and the rest of the apparatus was in an adjoining room. This prevented the experimenter from hearing more than a very slight click when he operated the sounders, which was in no way similar to the click of the sounders when heard in the same room with them. It will be observed that Do.'s results in this series conform to those of the other subjects.

Though improvement was manifested after work by three subjects, it was not nearly so great as after the rest interval. It may be that we have here, with the exception of the work of Do., the influence of physical fatigue not only upon the ability to discriminate the sounds, but also upon the memory process. This might mean that the learning process in the first test has been interfered with in some way by the physical work that follows, or that the recall in the second test has been affected by the physical fatigue. Mr. De Camp has conducted a series of experiments (as yet unpublished) * to determine the influence upon learning nonsense syllables of different kinds of work following at various intervals after the learning. The

* Since the above was written Mr. De Camp's work has appeared in Psychological Monographs, vol. 19, No. 4.

interval between learning and recall was usually only twenty minutes, and it might be possible in these experiments for fatigue to affect recall as well as to exert a retroactive effect upon learning. However, a part of the series were tested twenty-four hours after learning. In these, as well as in the series tested twenty minutes after learning, he found very little evidence of a retroactive influence when mental work was used. In the tests in which physical work was used after learning the tests showed a lower per cent of recall, but, as the physical work was always used in the short intervals, it is probable that it affected the results through the influence of physical fatigue on the recall, rather than that it affected the learning process. This is Mr. De Camp's interpretation of the results. If we accept his conclusions as applicable to our sounder test, then we find that physical fatigue has affected our test either by decreasing the power of discrimination or by interfering with the practice effects (recall) of the first test.

That interference with the practice effects is not the only influence of fatigue is demonstrated by the results of Do. Though after rest there was an average of only 4.2 per cent decrease in omissions, which was counterbalanced by 5.9 per cent increase in errors, he shows an average increase of 0.5 per cent in omissions and 14.1 per cent increase in errors after walking for two hours. Though S. improved greatly after rest, he shows as decided decrease in discrimination after the physical fatigue. Inasmuch as fatigue could influence the practice effects only to the point of rendering no improvement, these results must be due, in part, at least, to the direct influence of fatigue upon attention and discrimination.

The introspections of the subjects throw further light upon the nature of the processes with which the sounder test deals. In every case it was reported that the sound to be reacted to was held in mind and the other three sounds were dropped out. Confusion always resulted when the other sounds were not inhibited. In this the results and introspections uniformly agreed. To test the degree to which this inhibition process was effective, an extra minute was occasionally added to the second test without the knowledge of the subject, and only two sounders used, the one to which the subject was to react, and one other. In no case did the subject know what had occurred, though he usually realized near the end of the minute

that some change had taken place. It never materially disturbed his reactions. Be. reported that the three sounds were kept in mind, but were not clearly distinguished, that is, each sound had a number for her, and she knew whether it had been given as the reaction sounder, but otherwise the three were confused. For Do. the extra three sounds were generally scarcely more clearly present than any other slight noise that might occur, and when one was signaled as the sound to be discriminated, it came as a sound that had not been heard during the previous minute. Only one subject, a student whose results were too meager to be reported, found that he kept all four sounds clearly in mind. If he failed to do so he became confused.

The two types of physical work used with the sounder test should be considered separately. The "harness" represents a strenuous type of work that generates fatigue quickly. The subject is somewhat out of breath, feels weak in the knees, and is more or less in a tremor all over. The long walks develop fatigue much more slowly, and there is more time for a gradual readjustment generally. Moreover, physical fatigue produced by walking has more time, if time is needed, in which to affect mental ability. Two subjects walked, and one of them was used in the work with the harness. So there is a slight basis furnished for a comparison of the two kinds of physical fatigue. After the walks S. shows an unusual decrease in power to react correctly; this condition is fairly constant throughout the series. In only one test has he shown improvement in both the per cent of omissions and in the per cent of errors; in one other case he has improved in omissions but failed in errors. Usually a change in one form of mistake is paralleled by a similar change in the other form. This is not true with Do.'s results. The two forms are more inclined to fluctuate independently. His failure after walking is also not so marked as in S.'s results. It will be noticed that the per cent of mistakes in both tests for Do. on the last fatigue day is extremely low. It is difficult to account for this unusual drop. It was not the fault of the sounders, for S. was tested at the same hour, and his results are normal. The sounders were operated a little faster for Do. than was usual, and it may be that this acted as a stimulus to greater activity, or the fact that the sounds came closer together may have made them

easier to discriminate. Possibly this is merely an indication of unusual mental activity. If this was true in regard to his mental condition it certainly was not true in regard to his physical condition in the second test. Do. had walked three hours as rapidly as possible and had covered fifteen miles. Nausea accompanied his feelings of fatigue.

It is quite certain that the other subjects were considerably fatigued by the harness exercise, particularly W., who worked most conscientiously and whose curve fell gradually throughout the entire twenty minutes. More tests were taken with W. than with any other subject, but his results vary between wide limits. There seems to be no constant tendency in his results in the relation of omissions to errors; they neither vary together nor oppose each other. It will be noticed that the fourth rest day produced an unusually large increase in the per cent of errors and a considerable increase in the per cent of omissions. The eighth day reversed this and gave extremely large decreases in both omissions and errors. On the whole, however, the tendency is to decrease the improvement after physical work and the fluctuations are not so great. Do. shows a slightly greater decrease in the per cent of errors after the physical work than after rest, but the per cent of omissions has increased to a much greater extent after work than the omissions have decreased. Bt. shows a decided decrease in improvement after work and his daily records are fairly constant.

Be. manifests the greatest influence of physical fatigue. Her improvement after rest is uniformly great, and after fatigue she almost as uniformly falls below her record in the first test. Bu. is very irregular. It will be noticed that he frequently makes very few mistakes, and at other times makes as many as the other subjects. It is impossible to account for this extreme variability, as Bu. was always a conscientious, intelligent worker, and the tests were always conducted under as nearly the same conditions as possible. He was our youngest subject and of only sophomore rank. It is possible that his variability was due to lack of training.

A comparison of Do.'s results with the harness and with the walking indicates that the harness has reduced discrimination power as much as walking. If we consider the improvement after twenty minutes' rest, then the harness has had the

greater effect. It is unfortunate that we have two sets of conditions here, as it makes it uncertain whether the effect is due entirely to the mode of producing physical fatigue or to the possibilities of learning in the tests. However, it is certain that both modes of physical fatigue have decreased mental efficiency in a marked degree. All the subjects have shown some decrease in mental ability after physical work as tested with the sounders. This decrease has been greatest for Be. and S., and moderately large for Bt. The other subjects, except Bu., have been affected definitely. Bu.'s results are uncertain.

ASSOCIATION TEST.

As in the sounder test, any variation in speed that can affect in any way the accuracy of the association processes has been eliminated. The variations in the time of recall on the following day represent the degree to which the syllables had been learned, and do not indicate any possible changes due to the influence of fatigue upon the process of recall. The syllables were exposed at a regular rate after rest and fatigue periods and the only possible effect of the physical fatigue would be upon the learning process. The effect of fatigue upon the process of recall constitutes a distinct problem that should be studied, but the present series deals only with the influence upon the learning process as evidenced by recall after a period that is long enough that fatigue can not affect recall directly.

The per cent correct and the average association time for each day's test are given in Table IV*a*. As the fatigue days alternated with the rest days, the results for corresponding days are placed opposite each other in the first four columns. The per cents of increase or decrease for the fatigue days as compared with the results for the rest days are given in the fifth and sixth columns. The total per cent correct, and the average time, taken from the total scores, without reference to the individual days, are given in Table IV*b*, which also shows the number of cases used in determining the average time, and the number of cases in which the time was more than 10,000 σ and the number of cases in which it was less than 3000 σ. It should be remembered that the total number of cases given represents those responses that were correct or partially correct. The incorrect responses were not used in determining the average association times.

Four of the subjects have shown decreased learning power after the physical work. Of these, three not only have made lower scores but have required longer times for the recall. The fourth, Do., has a slightly shorter average time of recall after physical work, which seems to be due to the elimination of a few of the extremely long times. The average times after work for the other three subjects is due to a general increase in the time of recall. On the other hand, H. has a better score after work, but his average time is much greater, due in part to more extremely long times, but also due to a more general lengthening of the time. The results of E. are very doubtful. Two of the days following rest he has a higher per cent correct than on the corresponding work days, but the association time has been longer for these days. His average time is longer on work days in spite of a much greater number of extremely short times. Were it not for the fact that his averages here are very similar to results of his work in other experiments, to be reported in another paper, we might consider these results as of little value. The indications of these later experiments are that in a longer series of association experiments with physical fatigue the average result would have been approximately the same as it is here. Furthermore, we can not consider him as thoroughly fatigued after running two miles across country as most of the subjects were after their form of physical work, as E. was a regular track man in training at the time. H., who presents a consistently higher average after the long walks, was accustomed to long walks every day, and usually reported only slight feelings of fatigue. It is significant, also, that there is a general tendency with most subjects to make a greater effort to recall when learning followed fatigue. At least this is suggested by the generally longer association times and more extremely long times.

The results of R. deserve separate consideration, as they do not involve purely rote learning as the others do. Whereas all cases involving sensible associations were discarded in the other series, R. was allowed to form all the associations he desired. Nevertheless, his results were quite as consistent as those of the other subjects. In only one case has he made a better score after physical work than on the corresponding rest day, and then the association time is unusually long. Only two work days produced higher scores than the poorest rest

day. That the mental processes involved in learning a series on nonsense syllables as R. did are different from those employed in the rote learning by the other subjects, can not be doubted. At least they are more complex. The following are a few of the syllables learned and the associations by which they were connected:

bex hup; *bec*kons to hurry *up*.
gam cib; *gam*ble, punish at *Sib*eria.
roc gub; *roc*ks, money for *gub*ernatorial campaign.
wip cej; *wip*e, *see* just a little better.
huv cef; *hu*rry *v*ery fast to *see Eph*.

These are samples of the connections he formed. All the other syllables were connected by similar associations. Undoubtedly physical fatigue influenced these associations materially, as he shows the greatest effect of physical fatigue and more frequently reported difficulty in forming connections after work periods than after rest periods.

The results of M. are very uniform, with the exception of the scores for the first rest day and the first work day. There is nothing to indicate why these scores should be so low, as the practice series that preceded usually gave better averages. If we omit these two scores, the total averages would be 88.4 per cent after rest and 73.4 after work; that is, a little greater decrease in learning after work would be manifested. Br. and Do. show considerable tendency to fluctuate from day to day, but their scores are consistently lower on work days.

THE CURVE OF MENTAL WORK.

The addition and multiplication tests were divided into five-minute periods, and the sounder test into four-minute periods, in order to determine, if possible, the effects of inertia and fatigue within the course of the mental work of the test. The addition and multiplication tests could have been divided into smaller periods, but the variation in the difficulty of individual problems made the longer periods seem advisable. The time required to solve each problem was always recorded by the experimenter, and several curves were constructed by one-minute periods and by individual problems. These curves were so irregular and varied so widely from each other for the same individual that the plan was abandoned and the longer periods adopted.

The sounder test could not have been divided into smaller equal periods, for the four sounders presented unequal difficulties for discrimination.

The chief characteristic that is brought out by the subdivision of the addition and multiplication tests is the almost total lack of any constant tendency, either in the speed or accuracy of the processes. In Table I*a* one may find instances in the first tests that indicate that Ba. decreases speed after the first period and increases accuracy, but there are other instances in which he shows no such tendency. This is illustrated by the tests before rest and before running eighteen laps. In the second tests these series show the reverse arrangement. Co. (Table II*a*) manifests a constant speed in all averages of tests preceding the interval, and a fairly constant speed following the interval, whether it is after rest or physical work; but there is no uniformity in accuracy in either the first or second tests. Even the subjects that did more poorly in the second tests on work days do not show definite signs of fatigue in the first tests. In the results with the sounder tests (Table III*a*) there is a more definite tendency observable for some subjects. Bt. improves throughout the first tests, though his average in the second quarter is better than in the third in the series before rest. In the second tests his accuracy decreases until the fourth period. De. improves regularly in the first tests and in the first three quarters after rest, but the fourth quarter is lower than the first. After fatigue he decreases gradually in efficiency until the fourth quarter and then manifests a decided improvement. This might be due to a realization of the fact that he had been doing poorly and that the end must be near. All the subjects realized approximately the progress of the multiplication test. The other subjects, however, showed less definite tendencies, except that W. always did better in the first quarter of the second test and gradually decreased in the following quarters. It seems probable, therefore, that if such phenomena as the "antrieb" and the "anregung" do exist, they are, as Thorndike (39) finds them, purely occasional occurrences which lack any great importance. In general, a single test may be selected from any subject's series that illustrates any theory desired, but the average of several tests represents a blur. As was indicated earlier, the mean variation, if given, would be very large.

CONCLUSIONS.

One of the common fallacies in the study of fatigue, Squires (36) has pointed out, is to consider it as a simple phenomenon. It is true we may isolate a muscle and produce a fatigue that is relatively simple, but in the usual conditions of what we term fatigue we are dealing with a complexity that is difficult to analyze. If we accept Thorndike's definition of fatigue as "that diminution of efficiency which rest will cure" the problem seems simplified. But we still have to reckon with the physiological and mental factors that bring about this diminution of efficiency, and their relative influence is not always so easily determined.

We find that the effect of physical fatigue upon mental efficiency, as expressed by addition and multiplication, is very irregular. A subject may do better after a work period than after rest, or he may show an increase in speed and a decrease in accuracy. This agrees with the results of Ebbinghaus (10) and those of Heck (15) in their experiments on mental fatigue in school children. Again, the subject may improve after physical work in proportion to the amount of work done; thus, Ba. failed after rest, did less poorly after running eighteen laps, and improved after twenty-seven and thirty-six laps. The sounder and association tests, on the other hand, present more uniform results, and, in most cases, show a diminished efficiency after physical work.

Two theories present themselves as explanations of these results. (1) It may be that the fatigue products generated by the physical work, either in the motor neurones or in the muscles, spread through the circulation to the association centers and cause directly a diminution in the efficiency of the association processes; or, (2) it may be that the sensations that accompany fatigue serve as distractions and thus cause a decreased attention. The former view is partially borne out by the results. As in Ranke's (33) experiments the perfusion of an isolated muscle with a weak solution of sarcolactic acid caused a heightened excitability, so it is possible that a certain amount of physical work would produce a sufficient amount of fatigue substance to cause increased mental activity; a greater amount of this fatigue substance would cause a decreased mental activity. Ba.'s results (Table II*b*) would

then indicate that the increased physical fatigue caused by running the longer distance had transmitted to the association centers only relatively small amounts of fatigue products, though the motor system might contain much greater concentrations. We might, therefore, expect that he would show greater mental fatigue later, or after a greater degree of physical fatigue, than was reached in these experiments. It is doubtful, however, if this theory could be made to account for all the facts.

That physical fatigue may influence mental efficiency by virtue of its distraction power is evidenced by many little incidents during the course of the experiments and by the introspections of the subjects. In all but the association tests it was possible for the experimenter to mark the record during the course of the test whenever he wished to record any change in the conditions of the experiment. These records could then be checked with the report of the subject at the end of the test. It was found that what the subject reported to be a distraction affected his results in just the same way that it has been found that fatigue may do. Sometimes it caused a decrease in mental efficiency and at other times it caused an increase. Moreover, the results did not always agree with what the subject thought the effect of the disturbance had been. In general, a slight noise, such as the peeping of some chicks that were in the room at one time, or a person talking outside near the door, disturbed the subject, but increased his efficiency. On the other hand, louder noises, or longer continued disturbances, were apt to be accompanied by a decrease in efficiency.*

It is highly probable that physical fatigue operated as a distraction in much the same way. The accompanying sensation of physical fatigue and the general condition of the subjects after physical work may be gathered from their introspections. The following are representatives: "Felt shaky in legs, but not sleepy. Mind seemed clear." "Back and feet ached. Did not feel fatigued until about twenty minutes after I stopped physical work." "Could not keep results (multiplication) in mind. Arms seemed rigid at the end of the work

* Since the above was written a series of experiments to study the influence on the sounder test of various forms of distraction has been undertaken by Miss Berger in the Kansas laboratory. So far as the work has progressed the results seem to conform closely to the above casual observations.

period; then grew weak and numb." "Shoulders felt sore. General tension all over. Cobwebs seemed cleared away in second test." "Mind seemed clear at the beginning of second test, then felt a tendency to confusion. Felt drowsy in second half of the test. Legs tingled and hips ached." "Mind clear at first; then a tendency to sleep. Muscles of whole body seemed to be relaxing. Were tense at first." "Felt sleepy all over, *i. e.*, numb and quivery, particularly in legs. Could read the syllables easily, and mind seemed fairly clear, but the syllables seemed to make little impression." It will be seen that frequently the subject feels stirred up and active after the physical work. Or he may start the second test in that condition and then he notices the coming on of drowsiness and the general relaxation of the muscles. Sensations of strain have given way to sensations of relaxation or of rest, which seems to constitute the feeling of fatigue.

Shepard (35) suggests that "the content of sleep consists of a group of sensations of 'fatigue' or 'rest.' Sleep is a more complete rest. The process is a dominance of an organized group of these sensations. Such sensations from one part are associated with those from another. It is not that the sensations are aroused only at the time of sleep, of course, but that they become dominant in attention as any other group of sensations may be dominant in attention. This dominance is promoted by the intensity of the sensations themselves and by other conditions of attention." (p. 78.) This relation of the sensations of fatigue or relaxation to the mental condition is seen in the introspections. One subject reported that the arms seemed rigid, and so long as this condition of strain endured he was mentally alert. At least he experienced no tendency to drowsiness. We simply can not sleep when the sensations of strain dominate. But as the muscles begin to relax, drowsiness and consequent confusion result.

There remains the difference in the character of the results with the first two tests as compared with the last two tests to be considered. This difference can be accounted for by the effect of incentive. It is doubtful whether we ever do our best unless there is present something more than the vague purpose to do our best. A runner can run a little faster in a contest than he can alone, however hard he may try. Wright (47) found that a subject could do considerably more on the ergo-

graph when he was given a standard or incentive than he could do when he was merely told to do his best all the time. In the addition and multiplication tests there was no standard, or at best only a vague one, but in the sounder and in the association tests the subjects had to keep up to the standard of speed set by the experimenter, and he must keep mentally alert all the time in order to avoid complete confusion of the sounders. The result was less possibility of variation, and consequently less chance to obscure the effects of physical fatigue.

Though the addition and the multiplication tests are valuable tests, the sounder and association tests furnish the more reliable data in this series. The association test was thought to involve more complex processes, and it was expected originally that it would yield more readily to the effects of physical fatigue. However, the results do not differ materially. Further studies on the effect of physical and mental fatigue upon the attention and association processes are now in progress, and will be reported later.

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